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(19) (CA) **APPLICATION FOR CANADIAN PATENT** (12)

(54) Abrasion/Erosion Resistant Wear Alloy

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Notice: This application is as filed and may therefore contain an incomplete specification.



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ABSTRACT

5 An abrasion/erosion resistant wear alloy suitable for use in high or low stress applications having potential exposure impact loading which provides both good wear characteristics gained from a large volume of high hardness carbides in a tough, stable austenitic matrix which provides requisite ductility and which has the additional advantage of being work hardenable during service.

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## ABRASION/EROSION RESISTANT WEAR ALLOY

### FIELD AND BACKGROUND OF THE INVENTION

The present invention relates, in general, to erosion resistant wear alloys used in industry and, in particular, to an improved abrasion/erosion resistant wear alloy suitable for use in high or low stress applications potentially exposed to impact loading which can be employed in coal or mineral pulverizers or other types of crushing apparatus.

The removal of material from metal surfaces by coal and mineral fragments is a complex process. Several types of abrasive and/or erosive wear can occur in grinding equipment, including gouging abrasion, high stress grinding abrasion, low stress scratching abrasion, and erosion. Erosion is a separate wear mode, distinct from abrasion. Erosion is a ballistic process involving impingement of particles travelling with some velocity while abrasion involves sliding of particles under load over a surface.

Each of the above-described wear modes is influenced in a different fashion by the wear component's material properties and its microstructure. An extensive literature search revealed that in no case has a complete correlation been made between laboratory testing using any type of test method and a wear alloy's performance in the field.

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Several factors are relevant to the selection of a wear alloy for a given application. The following discussion involves selection of those properties for optimum wear alloy performance when used in the severe service environment of a coal pulverizer.

Wear alloy performance involves considerations of factors that affect both wear resistance and breakage resistance. Factors affecting wear resistance include: wear conditions, hardness, carbide volume fraction, matrix microstructure, and carbide morphology. Factors affecting breakage resistance include: load conditions, fracture toughness, austenite content of the matrix, internal stresses, carbide volume fraction (CVF), and carbide morphology.

As discussed in Steam: its generation and use, 40th Edition, Copyright ©1992 by The Babcock & Wilcox Company, at page 6-13, cast irons and steels (containing more than 2% or less than 2% C, respectively) have long had wide acceptance as wear resistant and structural components in boilers. The three types of cast iron used in boilers are white, gray and ductile iron. White cast iron is so known because of the silvery luster of its fracture surface. In this alloy, the carbon is present in combined form as the iron carbide cementite ( $\text{Fe}_3\text{C}$ ). This carbide is chiefly responsible for the hardness, brittleness and poor machinability of white cast iron. Chilled iron differs from white cast iron only its method of manufacture and it behaves similarly. This type of iron is cast against metal blocks, or chills, that cause rapid cooling at the adjacent areas, promoting the formation of cementite. Consequently, a white or mottled structure, which is characterized by high resistance to wear and abrasion, is obtained.

White cast irons can be obtained also through the use of suitable alloy additions. The addition of chromium for example is especially beneficial to cast iron wear properties. High chromium irons have an austenite (or some transformation product of austenite) matrix and an essentially discontinuous complex

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network of carbides. The  $M_7C_3$  carbide formed in these materials is considerably harder than the  $M_3C$  carbide found in most steels. The replacement of the iron carbide by chromium carbide has a dual effect on material properties. The  $M_7C_3$  carbide has a higher hardness than that of quartz, which is one of the most prevalent abrasives in many grinding operations. The higher hardness carbide, therefore, is more resistant to micro-cutting and removal by quartz particles. The morphology of the  $M_7C_3$  chromium carbide network is typically discontinuous, thereby yielding a less direct fracture path under impact loading.

A significant advance in wear alloy technology occurred in the late 1950s and early 1960s when Ni-Hard IV was developed by INCO. This material is essentially equivalent to B&W's Elverite I cast wear alloy developed specifically for use in pulverizers and other wear resistance parts. The alloy contains approximately 4-7% nickel and 8-10% chromium, which produces a discontinuous form of a complex carbide, thereby enhancing its fracture toughness. Subsequent to the development of the Ni-Hard IV, a range of alloys based on the ternary iron-chromium-carbon system with additions of molybdenum and/or copper to enhance hardenability were investigated both in the U.S. and in Europe. During this time period, detailed laboratory investigations determined the boundaries of the ternary Fe-Cr-C system, as shown in Figs. 1 and 2 which provided a concrete basis for the study and development of improved wear alloy materials.

The chemical compositions of high chromium cast irons typically produce a hypoeutectic alloy which solidifies with a primary austenite ( $\gamma$ ) matrix, as shown in Fig. 2. Depending upon the alloy chemistry and cooling rates, the matrix can be retained to room temperature or transformation can occur. The alloy can be further modified through the use of an austenite "destabilization" heat treatment cycle. This solution treatment precipitates secondary Cr carbides which reduces chromium and carbon levels in the austenite. Thus, upon subsequent cooling

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after destablization, a martensitic transformation will occur. A final tempering step is often utilized to further transform retained austenite within the hardened structure and to stress relieve and temper the already existing martensitic phase.

- 5 VAM 20°, a more recent development, is a 20% Cr white iron with a molybdenum addition which yields an essentially austenitic material in the as-cast condition. Subsequent thermal processing produces a material with a carbide-in-martensite matrix, very high hardness and good toughness
- 10 (compared to other white irons). The hardness and wear resistance of VAM 20° are superior to those of the Elverites and similar alloys in part due to the molybdenum addition which forms carbides which are harder than chromium carbide. It is always used in the heat treated condition, which accounts for
- 15 its good toughness and uniformity. VAM 20° is used in grinding elements of coal pulverizers.

The high Cr-Mo cast wear irons as defined in A.S.T.M. A532 Type IIE have the following chemical composition ranges:

Weight Percent

20	<u>Constituent</u>	<u>Range</u>
	Carbon	2.6 - 3.2
	Manganese	0.5 - 1.5
	Silicon	1.0 max
	Nickel	1.5 max
25	Chromium	18.0 - 23.0
	Molybdenum	1.0 - 2.0
	Copper	1.2 max
	Phosphorous	0.10 max
	Sulfur	0.06 max

- 30 The balance is essentially iron with the usual impurities.

Because the grinding of various materials such as coal requires significant capital expense in machinery and grinding

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wear elements, improvements in the durability and wear resistance of these components is a constant goal. It has thus become desirable to develop a new erosion resistant wear alloy suitable for use in such applications.

## 5 SUMMARY OF THE INVENTION

A review of the open literature coupled with an assessment of current wear alloys and their in-service performance has led the present inventors to conclude that wear alloy performance can be improved. In particular, improved performance can be  
10 obtained by:

- 15 (1) modifying the metal matrix by adding elements that stabilize certain microstructural phases (i.e., nickel, molybdenum and carbon are known to stabilize the austenitic phase in ferrous materials);
- 20 (2) using heat treatment to homogenize the metal and to stabilize desired microstructural phases; and
- 25 (3) increasing carbide hardness and volume using strong carbide formers such as vanadium, tungsten, niobium, tantalum or titanium.

The concept of improving wear performance by increasing carbide hardness has met with mixed results in the past. Currently there is a great deal of work was underway in Japan  
30 exploring this concept, and initially a great deal of work was underway in the United States and in Europe on this idea but, due to the varied and sometimes poor results obtained, work was abandoned by most U.S. researchers. It is also known that high

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volume fractions of metal carbides can cause embrittlement of martensitic materials under some conditions.

It is thus an object of the present invention to balance good wear characteristics, which can be gained from high carbide  
5 volumes and a hard matrix, against the ductility needed in the metal matrix to prevent cracking. Such ductility can be obtained by changing the matrix, i.e., from a martensitic to a stable austenitic matrix which can provide the requisite ductility and has the additional advantage of being work  
10 hardenable during service. In-service work hardening of the austenite matrix will be local to the surface and can provide additional wear resistance without sacrificing the component ductility that provides breakage resistance. The abrasion/erosion resistant wear alloy of the present invention  
15 is particularly suitable for use in high or low stress applications potentially exposed to impact loading. In contrast to stable austenite, it should be noted that retained, metastable austenite can be detrimental to wear alloy performance. Uncontrolled through-section transformation of the  
20 metastable austenite to martensite during service is undesirable because, a significant volume change occurs that can cause cracking.

Accordingly, one aspect of the present invention is drawn to an abrasion/erosion resistant wear alloy suitable for use in  
25 high or low stress applications potentially exposed to impact loading and having both good wear characteristics gained from a large volume of high carbide, together with a tough, stable austenitic matrix which provides requisite ductility and which has the additional advantage of being work hardenable during  
30 service, the alloy having a constituent composition consisting range essentially of:



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	<u>Constituent</u>	<u>Wt. Percent</u>
	Carbon	about 2.6 - 2.9
	Manganese	about 0.75 - 1.25
	Silicon	about 0.50 - 1.0
5	Nickel	about 0.5 max. .
	Chromium	about 25 - 28
	Molybdenum	about 1.0 - 6.5
	Copper	about 0.5 max.
	Phosphorous	about <0.08
10	Sulfur	about <0.05

with the balance essentially iron with the usual impurities.

Another aspect of the present invention is drawn to a particular composition for an abrasion/erosion resistant wear alloy of the type described above, the alloy having a particular constituent composition consisting essentially of:

	<u>Constituent</u>	<u>Wt. Percent</u>
	Carbon	about 2.75
	Manganese	about 1.00
20	Silicon	about 0.75
	Nickel	about 0.2
	Chromium	about 27
	Molybdenum	about 6.25
	Copper	residual amounts
25	Phosphorous	residual amounts
	Sulfur	residual amounts

with the balance essentially iron with the usual impurities.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the present invention, its operating advantages

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and specific results attained by its uses, reference is made to the accompanying drawings and the following description in which preferred embodiments of the invention are disclosed.

#### BRIEF DESCRIPTION OF THE DRAWINGS

5 In the drawings:

Fig. 1 is a drawing showing the austenite liquidus surface of the Fe-Cr-C system; and

Fig. 2 is a drawing showing a corner of the metastable Fe-Cr-C liquidus.

#### 10 DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following discussion includes a description of the range and preferred compositions of the abrasion/erosion resistant wear alloy of the present invention. It is to be emphasized that this particular abrasion/erosion resistant wear  
15 alloy is suitable for use in high or low stress applications having potential exposure to impact loading. It provides both good wear characteristics gained from a large volume of high hardness carbides, and a tough, stable austenitic matrix which provide requisite ductility and which has the additional  
20 advantage of being work hardenable during service. The alloy has a composition consisting essentially of the following elements as set forth in the table below, the first column being the particular constituent, the second column being the preferred range in weight percent of these constituents, while  
25 the third column represents the preferred particular composition weight percents of these constituents.

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Weight Percent

	<u>Constituent</u>	<u>Range</u>	<u>Preferred Composition</u>
	Carbon	about 2.6 - 2.9	about 2.75
5	Manganese	about 0.75 - 1.25	about 1.00
	Silicon	about 0.50 - 1.0	about 0.75
	Nickel	about 0.5 max.	about 0.2
	Chromium	about 25 - 28	about 27
	Molybdenum	about 1.0 - 6.5	about 6.25
10	Copper	about 0.5 max.	residual amounts
	Phosphorous	about <0.08	residual amounts
	Sulfur	about <0.05	residual amounts

The balance is essentially iron with the usual impurities. In the above range and preferred compositions, the carbon is added to increased carbide volume and alloy hardness. The manganese is added to control cleanliness (i.e., scavenging embrittling elements such as sulfur). The silicon promotes castability while the chromium promotes carbide formation. Finally, the molybdenum stabilizes the austenitic matrix and forms additional high hardness carbides.

The abrasion/erosion resistant wear alloy can be used as-cast. Alternatively, the alloy can be heat-treated or the composition can be changed within the range and coupled with other material processing can be made to develop an austenitic and/or martensitic structure tailored to a variety of wear conditions. For example, when erosive wear conditions predominate, a martensitic matrix may be preferable. Similarly, under more abrasive conditions, a more austenitic structure may be preferable.

It is preferred that the present invention be heat treated according to a two-step process, the first step during manufacture being an austenization step carried out in a temperature range of approximately 1750°F to 1950°F, the preferred temperature being approximately 1850°F, for a

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sufficient time to thoroughly homogenize the metallic structure throughout the parts being made. This step is important in obtaining a completely stable austenitic matrix.

The second step is a lower temperature tempering step  
5 carried out in temperature range of approximately 500°F to 1000°F, the preferred temperature being approximately 950°F, again for a sufficient time to thoroughly homogenize the tempering effects throughout the parts being made.

Another important aspect of the chemical composition of the  
10 present invention is that the relative nominal levels of Manganese (Mn) and Silicon (Si) are maintained such that the weight percent of Mn is greater than the weight percent of Si, i.e., that a ratio of Mn/Si is greater than 1.0. This is important because the manganese addition offsets the loss of  
15 material toughness caused by the presence of silicon in the alloy. Whereas silicon is necessary to promote castability by improving liquid metal fluidity; some amount of brittleness is imparted to ferrous alloys by silicon additions.

The present invention provides large carbide volume  
20 fractions and high carbide hardness promoting good wear resistance. The austenitic matrix provides good resistance to cracking and breakage resistance and the added benefit of being able to be work hardened at the surface during service. This promotes wear resistance without impairing ductility. The  
25 abrasion/erosion resistance wear alloy of the present invention can be used to produce components having substantially longer service life, thereby reducing maintenance and replacement costs. Particular applications where the present abrasion/erosion resistant wear alloy can be used includes coal  
30 pulverizers or mineral crushing equipment wear surfaces for both abrasion and erosion-resistant applications

It will be further appreciated that although the present abrasion/erosion resistant wear alloy is intended for use in coal grinding and pulverizing equipment, other erosive material  
35 handling systems and the like may benefit by employing this

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alloy. It can also be used for other applications where wear resistance is needed. Examples would include shot blasting equipment, mining equipment, and slurry transport. Accordingly, while in accordance with provisions of the statutes there have  
5 been described herein specific embodiments of the invention, those skilled in the art will understand that nominal changes may be made in the form of the invention covered by the appended claims to enhance its use in various settings, and that all such modifications and improvements have been deleted herein for the  
10 sake of conciseness and readability but are properly within the scope of the following claims.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An abrasion/erosion resistant wear alloy suitable for use in high or low stress applications having potential exposure to impact loading and having both good wear characteristics gained from a large volume of high hardness carbides and a tough, stable austenitic matrix, which provides requisite ductility and which has the additional advantage of being work-hardenable during service, the alloy having a constituent composition range consisting essentially of:

	<u>Constituent</u>	<u>Wt. Percent</u>
	Carbon	about 2.6 - 2.9
	Manganese	about 0.75 - 1.25
	Silicon	about 0.50 - 1.0
15	Nickel	about 0.5 max.
	Chromium	about 25 - 28
	Molybdenum	about 1.0 - 6.5
	Copper	about 0.5 max.
	Phosphorous	about <0.08
20	Sulfur	about <0.05

with the balance essentially iron with the usual impurities.

2. An abrasion/erosion resistant wear alloy suitable for use in high or low stress applications having potential exposure to impact loading and having both good wear characteristics gained from a large volume of high hardness carbides in a tough, stable austenitic matrix which provides requisite ductility and which has the additional advantage of being work hardenable during service, the alloy having a particular constituent composition consisting essentially of:

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	<u>Constituent</u>	<u>Wt. Percent</u>
	Carbon	about 2.75
	Manganese	about 1.00
	Silicon	about 0.75
5	Nickel	about 0.2
	Chromium	about 27
	Molybdenum	about 6.25
	Copper	residual amounts
	Phosphorous	residual amounts
10	Sulfur	residual amounts

with the balance essentially iron with the usual impurities.

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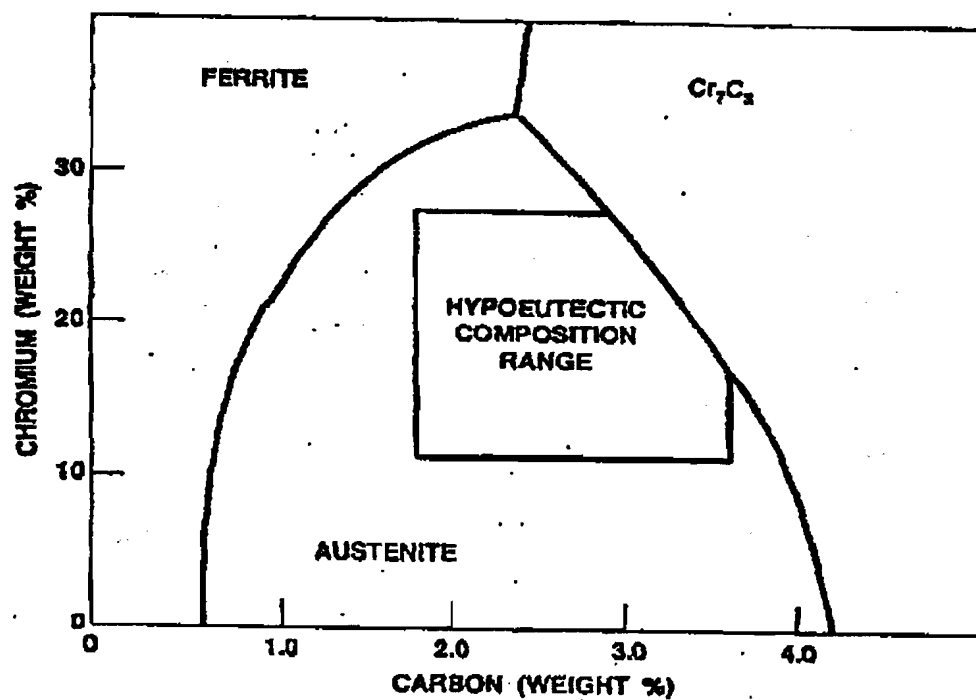


FIGURE 1 AUSTENITE LIQUIDUS SURFACE OF THE Fe-Cr-C SYSTEM



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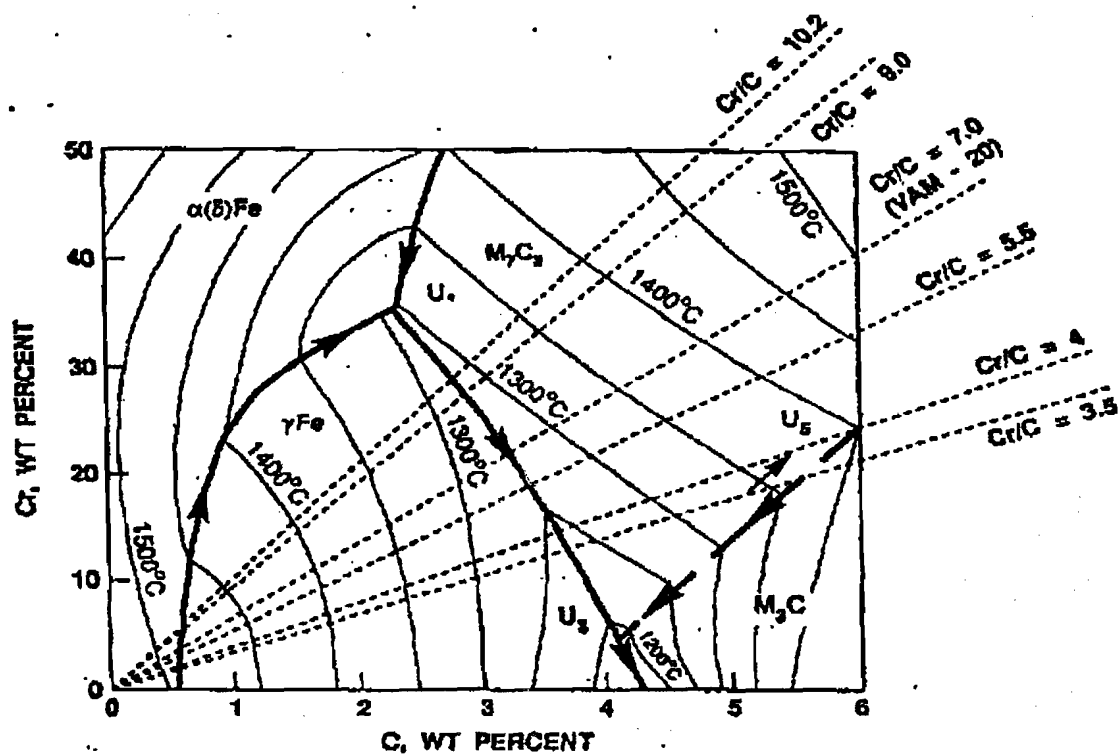


FIGURE 2 A CORNER OF THE METASTABLE Fe-Cr-C LIQUIDUS